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REMARKS ON THE QUANTITY, RATE OF CONSUMPTION AND PROBABLE DURATION OF NORTH AMERICAN COAL, AND THE CONSEQUENCE TO AIR-BREATHING ANIMALS OF ITS ENTIRE COMBUSTION.

BY ISAAC J. WISTAR.

The object of this paper is to attempt a calculation of the existing quantity of available coal in North America, the present and prospective rate of its consumption, its probable duration, and some of the physical consequences of its entire combustion. As much labor has been bestowed on the United States Census returns of 1889, being the year reported upon in the Census of 1890; and as under legislation of unprecedented stringency its officials have enjoyed an unusually favorable opportunity of demanding and obtaining a great number of reports from every quarter of the country, the figures and conclusions of that Census have been followed where applicable, though not without grave doubts that its statements respecting the carboniferous area may be optimistic and excessive, and regret for its silence on the equally important subject of thickness and quantity.

The entire carboniferous area of the United States including the post carboniferous beds of Virginia and North Carolina, but excluding the doubtful, much eroded and partly ruined beds of the Rocky Mountain territory, as to which scarcely an estimate is, or could now properly be ventured, is given at 219,080 square miles, being larger than any former estimate. By the carboniferous area is meant, however, not the area of mineable coal or any approximation or reference to it, but the whole of that area over which the rocks of the carboniferous series (excluding the subcarboniferous of geologists), as indicated by their relative position, petrology and fossils, come to and constitute the present surface or are within reach of its mining operations. A large proportion of this area never did contain coal, and another portion has long since lost whatever it once contained, the first in consequence of local failures of the original deposits, and the last because of subsequent foldings and contortions, followed by the erosion and loss of their upper or anticlinal folds. In all parts of the coal fields, areas of original barrenness are extensively interspersed, and in much of the richest coal district of Pennsylvania, the seat of maximum disturbance, and to a less extent, in other portions of the field, minor areas are found where large portions, sometimes amounting to more than two-thirds of the original beds, have been carried bodily away along with their adjacent protecting rocks, the detritus now resting far out on the sea bottom, or scattered along the ancient channels of drainage long since obsolete and covered deep with foreign material.

Again, much of the coal which has escaped this ruin possesses little or no present or future economic value because of such reasons as the following:

1. Its crushed and impaired condition, due to repeated and excessive flexures, overturnings and fractures.
2. Its detached position in small separate residuary basins caused by erosion and entire loss of the adjacent anticlinals, thus forbidding the permanent application of the large amount of capital required to exhaust such small separate areas.
3. The thinness of many of the beds, which do not, and never can admit of mining by any process of extraction, without removing more rock than coal.

Nothing need be said of mere depth, since the article being one of prime necessity, as it becomes scarcer it will be mined at all depths, the increased cost being compensated by advanced price. In England there is no doubt that if the "South Eastern bed" shall be satisfactorily verified, it will be immediately mined though its most ardent advocates give it a minimum depth of 3000 feet.

Nevertheless it is evident that large deductions must be made from the area of the carboniferous measures as these are known to geologists and adopted in the Census reports, before even an approximate knowledge can be reached of the extent of actual coal beds, adapted, as respects separate area and thickness, to supply remunerative coal at this or any future period. How large such deductions should be, we possess at present insufficient data for computing with accuracy, but from the general observations now possible to make, and from the well known tendency of many property owners to exaggerate the resources and value of their possessions whether in reports to Census officials or miscellaneous observers, we may be sure they must be sufficiently large to effect a very material reduction of the general area of the measures, before arriving at the actual area of mineable coal.

It would therefore seem quite a liberal estimate if such reductions were offset against the following items not included in the Census report, viz:

1. The detached basins of the Rocky Mountain region, chiefly of post carboniferous date, which, though occurring over an extensive territory, are mostly thin, small, widely separated, and often of indifferent quality.

2. The inaccessible and inconsiderable coal of the Arctic and tropical regions.

3. The relatively small beds of Nova Scotia and British Columbia.

After allowing such set off, and accepting the Census statement of the remaining carboniferous area as equivalent to a veritable area of mineable coal, we should have the latter fixed for the entire continent of North America at 219,080 square miles, which most practical geologists will probably only consent to accept with grave doubt, especially as no less authority than Professor Dana calculates the extent of the coal bearing area of the carboniferous measures exposed in the United States at 190,000 square miles, of which only 120,000 have workable beds of coal; and for the whole of North America at 208,000.* It is not desired to intrude here too much individual opinion, but after enjoying considerable opportunity of personal observation of the great coal; fields of the United States, Nova Scotia and British Columbia, I do not myself believe that the entire carboniferous exposures in North America contain 150,000 square miles of actual coal beds, including all qualities and thicknesses. Nevertheless it should be remarked in this connection, that though no out-crops or other of the usual external indications have been found, it is possible—though scarcely probable—that some of the upper beds of the carboniferous series extending westerly from the theatre of its greatest development, may underlie the rocks of later horizon constituting the great western plains. But it is well known that the lower members of the true coal measures thin out and disappear in going west from Pennsylvania, until in the first tier of States west of the Mississippi, only the highest beds in general remain, and if these should continue to decline toward the west in any such proportion as they do east of the great river, they must entirely disappear long before reaching the territory occupied by the cretaceous and later beds of the Rocky Mountain district.

Of this assumed continental area of 219,080 square miles of coal bearing territory, the available data for calculating the average thickness with precision is as yet extremely imperfect. The rocks of the coal measures proper, excluding the lower or Millstone grit section (generally known in Pennsylvania simply as "the conglomerate"), have an aggregate thickness "varying from 100 to 1000 feet in the Interior coal areas, to 4000 feet where greatest in Pennsylvania, and over 8000 feet in Nova Scotia.†

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*Manual of Geology, pp. 293.

The general tendency both of the measures and the interstratified coal seams, is to thin off from N. E. to S. W. across the entire territory of the United States, the lower or largest beds gradually disappearing, until in Texas only the top or latest member of the series is present, showing both at the Gordon and the Strawn mines, a maximum thickness of but twenty-two inches. General sections everywhere show thick beds of conglomerates, sand and sometimes limestones, and slaty shales with comparatively thin seams of coal. An extremely favorable section from Western Pennsylvania, taken from Lesley by the last quoted authority, shows in 810 feet of aggregate thickness, a total thickness of coal amounting to 25 feet in eight seams or beds, of which but two, one of six, the other of eight feet, are workable. While every proportion exists between the thickness of the measures and that of the contained coal, as well as between the coal seams themselves, the above is a fairly illustrative section from the best carboniferous field in the United States except the anthracite, which in the most valuable portions of the field probably averages a greater richness. The coal seams themselves though frequently extending continuously and perfectly identified for miles, vary in thickness from an extreme maximum of thirty feet to nothing, even the largest often thinning out over long distances to a meagre layer of carboniferous slate or dirt. In the Lykens Valley Coal Company's operations, for instance, in the lower or Lykens bed at Short Mountain, an extensive and hitherto reliable seam of ten feet, suddenly "pinched" out to such a trace, and was followed through the rock at heavy cost of time and money for over 6000 feet, before it resumed sufficient thickness for mining. These excessive and sudden eccentricities in thickness and value, though occurring to some extent throughout all the coal fields, abound especially in the anthracite district of Pennsylvania, that being eminently the region of contortions, faults, foldings and disturbances, which in fact accompanied or caused the metamorphism by which coal of ordinary volatility, was refined into anthracite. The general continuity and identity of coal seams, accompanied by frequent changes in thickness and value, is what might have been antecedently expected as soon as the geological history of coal became certainly known. At the time of the coal deposits neither the Allegheny nor the Rocky Mountains existed. South and west of the Green Mountains of Vermont the continental area was flat and low and being without adequate drainage constituted here a vast swamp, there a succession of small morasses, constantly enduring slow and slight changes of elevation ; now for a time and in places sufficiently above water to permit the growth of the redundant flora incident to such conditions, then sufficiently below to destroy vegetable life and cover its remains with deposits of sand of varying thickness, sometimes in fresh, sometimes in sea water. In some places ages elapsed before another emergence made renewed vegetable growth possible, in others subsidences and emergences succeeded each other with comparative rapidity, as now evinced by the respective thickness of the carbonaceous beds and the intervening sandstones, as well as by the succession of fossil species of plants and animals.

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† Ibid. pp. 309.

Thus the secular succession and separation of the coal seams, and the large proportion of those whose thinness deprives them of economic value is intelligibly explained by the then condition of land and water over this area, and the repeated though slow and slight changes in their relative level, while the destruction of a large part of such seams as were once valuable has been plainly due first to the extensive and violent disturbance of which the condition of the beds themselves supplies ample evidence, and next to more recent erosion on a stupendous scale.

It is unnecessary to dilate upon these elementary and well-known circumstances, because they have been for a long time very completely established and are fully set forth in all standard works on the subject, but so much seemed essential to remind the reader of the causes of the preponderance of thin and worthless seams, of the great irregularity both in thickness and condition of the comparatively few workable ones, the injury and even ruin sustained by many, and finally of the tremendous destruction and loss by erosion.

While there is a large amount of detached information available respecting the number and dimensions of workable seams at various points, there has been no such systematic collation of them as may serve for any precise generalization susceptible of proof, nor is it probable that such will be possible for some years to come. Nevertheless by comparing the best verified of these, with personal observation and the result of individual inquiries, one may venture upon an approximation subject to correction as time goes on and precise information becomes more abundant and available. If the problem were presented to practical American geologists, supposing the valuable coal remaining in all workable seams were distributed in a single bed of uniform thickness extending over the entire area, not of coal, but of the carboniferous measures, assumed at 219,080 square miles, what thickness should be assigned to it?, their reply must, as has been seen, be largely hypothetical. Yet being based on the several sources of information above referred to, it would possess value as the opinion of a large body of close and intelligent observers who have given careful observation and study to the subject as the most interesting of their lives.

It is the belief of the present writer that the majority of such observers would assign a thickness considerably less than six feet. But assuming six feet to be an admissible working estimate, and assuming the received quantity of 800 tons of 2240 ℔s. each, (about 42 per cent.), as that which is on the average mineable per level acre per foot of thickness, we should then by a simple arithmetical process get the following, viz: 219,080 square miles equal to 140,211,200 acres, multiplied by 6 feet (of thickness) and by 800, being the available tonnage, per foot of thickness from each acre, would give the tonnage, which is 673,013 millions of tons.

The same Census report states the production (and therefore the consumption) during the year 1889, at 141,229,513 short tons of 2000 ℔s. each, which is equivalent to 126,097,779 long tons of 2240 ℔s. each, and further states the increase of consumption to have been at the rate of 97.57, or in round numbers 100 per cent. per decade.

This rate of known actual increase applied to the present annual consumption for thirty years, then reduced to fifty per cent. per decade for the next forty years, and further reduced to thirty-three and a third per cent. per decade for another forty-two years, would indicate the entire consumption of every accessible ton at the end of 112 years from the year reported on, or say by A. D. 2001.

Of course the above is a broad generalization of results which will probably be reached about the same time but in a different manner. It is probable the rate of annual increase of consumption would during the first half of the period show a much more rapid acceleration, owing to the increase of population, to exportation, and to the constant new applications of steam power to old and new purposes, and that during the last half of the period it would decline more irregularly, and upon the whole more quickly, in consequence of the completed exhaustion of the more densely populated coal fields, the increased transportation required to distribute the fuel from the more distant ones, and the consequent growing scarcity and higher prices. But take any reasonable rate of increase we may, based on even a partial continuation of existing facts, and distribute it how we may over the century, and the general result will be about the same, viz: practical exhaustion in little more than three generations.

To such minds as may incline to the acceptance of these conclusions as a fair deduction from facts some of which are known and others derived from cautious and reasonable estimates, but of which only a portion are at present susceptible of proof, it will be at once apparent that certain consequences, both economic and physical, must ensue of the very highest importance to the human race and to all animal life: since the latter, except as regards the domesticated and protected species, tends to increase or decline in inverse proportion to that of man, the universal enemy. The former class of consequences belongs rather to the province of the statesmen and the publicist, though it may be pertinent to refer in passing to the general popular conviction with which such reflections are often brushed aside, i. e. that some new "force" or "power" of Nature is likely to be discovered and harnessed into human service long before the happening of an event that is admitted to be at least a century distant.

But if on examination it be found that there exists no intelligent ground for such expectation, then, however agreeable and consolatory, it must be taken as mere optimism, ready to find ease in any baseless and visionary possibility rather than face a fact which as all see, must sooner or later deprive our race of its most useful and effective asset, and materially change all the conditions of civilization, including its capacity to sustain population.

Now on attempting any such examination almost the first circumstance to be noted is, that as no new or previously unknown "force" has ever yet been discovered, it is very improbable,—if not demonstrably impossible—that any such force can exist in Nature without evidence of its presence. The existence and potentialities of all known forces of the kind such as steam and electricity, were never concealed and have always been known since the first pot was boiled or the first savage was struck by lightning.

What has been discovered is not those, or any other "forces," if we must continue to call them so, but practical and useful methods of eliminating and applying them to our work; and down to this present time that can only be accomplished by the combustion of fuel, without which we know of no way to produce any of them, on a large and useful scale, and at times and places where they are required.

On the contrary there are certain weighty reasons for believing that there can be no considerable unknown power lying concealed anywhere in Nature. For any such power must be either useful or useless in carrying on Nature's operations. If the latter, it must long since have ceased to exist, for nothing that is useless long survives without human protection. But if useful, then it must be an active and perturbing agent, exerting a useful and necessary function of some kind in Nature's laboratory and workshop. But while we can account for, explain and even predict, all great natural phenomena from the smallest chemical reaction to the most stupendous electrical, astronomical and meteorological events, and can even calculate the movements of our earth and all astronomical bodies, tracing every perturbation or eccentricity to its cause, there is no evidence of the function or action of any mysterious or unknown force, no concealed perturber whose mysterious existence and action disturbs our calculations and frustrates our predictions. Then none exists; and all that is left for us to consider is how to reduce to our service those forces that are known, without the use of fuel or artificial heat. Steam and decomposed water must be banished from the available category, for both are simply results of heat, of which, by terms of the supposition, there would remain no useful supply except as it was obtained by the first brain-developed anthropoids, directly from the sun.

There remains for consideration electricity, which may be obtained in minute quantity from chemical reactions, but its production on a useful scale by such methods, is at present inconceivable, unless by the prior production and handling of such vast masses of expensive material as to rob the result of all economic value.

It is even probable that the effective power obtainable from the gravitation of water, is not so great as is often assigned it, even in the most favorable climates. The area of Pennsylvania is 45,000 square miles, or 28,800,000 acres, and the extremes of precipitation on its eastern and western parts may be averaged at 39 inches, of which at least one-fourth, or ten inches, is lost by evaporation. The entire amount of its rainfall would therefore amount to 31,449,600,000,000 gallons per year, or an average of 86,163,287,671 gallons per day. Hence by the received formula $Q = 62.15\ A\ [\frac{4}{5}\ R—E]$, where Q is the daily supply in gallons, A is the catchment area in acres, R is the average annual rainfall, and E the loss by evaporation, both in inches,* is obtained the collectible quantity in Pennsylvania, viz: 41,526,144,000 gallons per day. Assuming that one-half of that quantity reaches the surface at a useful height above sea level and could be all converted into effective power with an average head of 150 feet, the total available power expressed in horse powers would be 524,320 HP per day, being equal to the power obtained by the combustion per year of 3,075,698 tons of coal of 2240 ℔s. each, which is probably less than one-tenth of the tonnage actually required and consumed in Pennsylvania to-day.

There are, however, certain conceivable physical results that may and to some extent must follow the combustion and dispersion in the atmosphere of all the carbon now fixed in a form available for fuel, which, though perhaps not at present fully computable, are of the very highest consequence. It may be safely assumed that such carbon, as well as that which is fixed in the calcareous or other carbonates, was for the most part so fixed long after the earth had condensed to its present form and dimensions and had cooled sufficiently to acquire a stable crust. Before that time the greater part or all of such carbon had existed in atmospheric suspension and whenever these compounds shall be resolved it must return to and remain in the atmosphere, until again fixed by the slow and gradual medium of chemical reaction in one case and the operations of vegetable life in the other. Since, however, our present concern is with the coal, the end of which, however more or less remote, we can with certainty foresee, let us endeavor to calculate, though with much necessary recourse to hypothesis, whether any appreciable effect on the atmosphere and on animal life is likely to follow the return to the atmosphere of the carbonaceous constituents of all accessible coal now and for ages past safely contained in the storehouse of the earth. The composition and weight of the existing atmosphere as well as of coal being well known, the first step necessary for such a calculation is to get a world-wide estimate of the quantity of such accessible coal.

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* Theory and Practice of Hydro-Mechanics, Inst. C. E. p. 44, cited in Ency. Brit., article " Water Supply."

Sir Charles Lyell and the early geologists at first supposed that the enormous geological destructions and reconstructions of which they observed the evidences everywhere on the land surfaces of the globe, had equally affected all surfaces, involving the subsidence of continents and the corresponding elevation of sea bottoms, in short a wide and perhaps universal and repeated interchange of continental and oceanic areas. But it has now long been known and in fact proved by the researches of the Challenger expedition and other investigations, that those early views were erroneous, and that notwithstanding the repeated changes of height and level everywhere and at all times prevailing over and throughout all land surfaces, the existing proportions between land and ocean areas have in the main always been maintained at least outside the depth line of 1000 fathoms. The evidence of this important fact is abundant and conclusive, but as it has recently been lucidly summed up in the latest work of Mr. A. R. Wallace,* it need not be repeated here.

Accepting these better modern views, it is clear that under the main portions of the ocean, neither derivative rocks nor fossil vegetation are to be looked for, and cannot exist in appreciable quantity. But the area of the entire land surface of the earth with its included waters, bears to the entire oceanic area the proportion of 28 to 72, according to the careful computations of Mr. John Murray, cited and approved by Wallace, a proportion which, as shown by Mr. Wallace's map of the 1000 fathom line, would not be materially modified if the littoral portion of the sea bottom lying inside that line should be tranferred from the oceanic to the land area.

Now since, as before observed, we possess accurate knowledge both of the constituency of the atmosphere as now existing, and also its weight both as a whole and per square foot of the earth's surface, we only require to know the quantity of coal existing on 28 per cent. of the earth's surface to compute the quantity of carbon originally taken by it chiefly from the atmosphere, and conversely, the quantity that will be returned to the atmosphere on the combustion of such coal, making a reasonable allowance in the last case for such portion of the coal as is inaccessible to man and can therefore never be consumed through his agency.

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* Darwinism, pp. 341–349.

The following computations bearing on this point and graduated to meet several different estimates of quantity, have been made with the assistance of Mr. B. C. Tilghman, an accomplished young chemist of experience and capacity and a member of this Academy.

The oxygen of the atmosphere, 23 per cent. by weight (or about 21 per cent by volume), if all burned into carbonic acid would produce 682·56 lbs. per square foot of earth surface. This would correspond to a weight of 185·76 lbs. of carbon in suspension per square foot of earth surface, and at a specific gravity of 95 lbs. per cubic foot (the average for anthracite) would correspond to a stratum of carbon 23·45 inches thick over the entire earth surface or to 83·71 inches thick on the land surface, assumed at 28 per cent. of the whole. With the aid of Mr. Tilghman the following tabular statement has been constructed from these data, which are repeated in its first horizontal line.

I	II	III	IV	V	VI
Percentage of atmospheric oxygen consumed.	Weight of carbonic acid produced per square foot of all earth surface. Pounds CO_2	Weight of carbon consumed per square foot of all earth surface. Pounds C.	Percentage of present weight of atmosphere corresponding to the weight of carbonic acid in column II.	Thickness of stratum of carbon required over entire earth surface. Inches.	Thickness of stratum of carbon required over land surface only. Inches.
100	682·56	185·76	31·60	23·45	83·71
2	13·650	3·714	·632	·4690	1·6742
1	6·825	1·857	·316	·2345	·8371

The first horizontal line of the table represents, merely as a basis, the theoretical results of a total absorption of all free oxygen by carbonization, for which, however. all the available accumulations of carbon that we know of are of course inadequate; for the return to the atmosphere of the carbonic acid formerly subtracted from it and now fixed in such carbonates as limestones, marbles, chalks and corals, cannot be looked for without the recurrence of such intense heat as there is no longer reason to expect, while on the contrary, the secular diminution of both solar and internal heat must tend to increase rather than diminish the stability of those compounds.

But the lower horizontal lines of the table, or some condition intermediate between them, approximate so nearly to the actual quantity of existing and available carbon accumulations assumed in column VI, that on the entire combustion of such accumulations nothing less can be looked for than the atmospheric modifications indicated in the preceding columns. The last line for instance, shows that assuming all the mineable coal of the earth to equal one stratum of ·8371 of one inch uniform thickness covering the entire land surface (this being taken at 28 per cent. of the whole) its combustion would abstract one per cent. from the existing twenty-three per cent. of all atmospheric oxygen and add ·316 of one per cent. of its present weight to the atmosphere in carbon dioxide.

We are not without means of verifying to some extent this assumed thickness of the supposed universal stratum of carbon. In North America we have seen that the total computed quantity available is 673,013 million tons, a quantity which, if equally diffused over the North American continental area of 7,400,000 square miles, would give a uniform thickness of ·924 of one inch. Since the conditions of the carboniferous period have at one time or other been common throughout all parts of the land surface of the globe as proved by the universal diffusion under similar conditions of coal or fossil vegetation, it would not seem a violent assumption to suppose that when we shall be as well acquainted with the other parts of the world as we now are with North America, it will be found that coal is not on the whole very unequally distributed, and that the tolerably well ascertained fact of the equivalent stratum for North America approximating an inch in thickness, will not be found materially different in other parts of the earth's land surface, and may at least be taken at ·8371 of an inch as indicated in the lowest line of the tabular statement, with all the other facts stated in the same line as appurtenant.

But just as the original abstraction of carbonic acid from the air by the carboniferous vegetation has certainly once modified to some extent or other all then existing life and rendered possible the evolution of higher forms, so the converse process, though to a less extent—since all coal is not accessible to the destructive power of man—must tend to restore the atmosphere to its precarboniferous condition and to some extent, however minute, impair or restrict its capacity for sustaining the higher forms of animal life as now constituted.

The data and proportions supplied in the table may of course be applied to such assumption of absolute quantities as may best satisfy individual minds. But its proportions are correct, and on any supposition it furnishes proof that some amount of deleterious influence must be exerted on the atmosphere, and therefore on the physical constitution and qualities of all air breathing animals and especially on the higher forms, which, being most specialized, are the least adaptable.

If it be objected that it is not to be accepted without specific proof that all of this carbon dioxide was at any one time in atmospheric suspension, then we have to suppose some agency of constant and steady supply during the enormous vegetable demand of the prolonged carboniferous period. This agency could only have been a vast and long continued amount of internal heat either diffused by steam, or occurring sufficiently near the surface to permit egress. Such heat would have been necessary to expel it from the carbonates in which it had been previously fixed, and must have been at the same time sufficiently intense to fuse and decompose limestone, and yet of a character consistent with the most profuse vegetable growth that has at any period occurred on the earth.

Nevertheless the suggestion is not beyond the bounds of possibility. Large quantities of carbon dioxide have always been, and now are being constantly emitted from the deep recesses of the earth's mass and constitute an essential part of the existing conditions of respiration; and it may be conceded that such dissolution of carbonates and evolution of carbon dioxide may have prevailed to a greater extent than at present before the earth's crust had cooled *at all points* to present temperatures, and may have aided the supply furnished from the atmosphere. But that the process was sufficient of itself to account for the great quantities that were fixed in the coal beds during the carboniferous period is not credible, because not supported either by the comparative absence of such process before and after that period, or by such amount of evidence as in that case should have left its traces everywhere among all accessible metamorphosed rocks.

It has been suggested that such future accession of carbonic acid to the atmosphere diffused over a century or more, may be met and counteracted by the consequent increased activity of tropical and other vegetation. There is no doubt that as long as the earth continues otherwise fitted to sustain life, we may confidently expect that in the future as in the past, new creatures will be evolved to meet new physical conditions. But there is reason to believe that vegetation, composed as it is of all existing individuals, has fully adapted itself to present conditions including the actual quantity of carbon dioxide heretofore and now being supplied from its own dissolution and decay, and from such sources of natural supply as the breath of animals, forest, prairie and accidental fires, volcanic combustion, subterranean decomposition and others of the kind. The amount of heat and moisture, the principal conditions of vegetable life, is more likely to decline with the slow diminution of solar vigor than to increase, and there is no reason for supposing that the present rate of vegetable growth is in any degree limited or restricted by the want of carbonic acid. If then the quantity, already sufficient, continues to be daily augmented by the ever increasing artificial combustion of coal, its entire absorption by vegetation would require a new and distinct modification in vegetable life. But any such adaptation must proceed in accordance with fixed laws, which never halt or vary to save individuals or species. On the contrary, their inexorable march even toward higher forms involves the remorseless extinction not only of individuals but of whole species, genera and orders, an evolutionary process which would doubtless have kept even pace with the slow *natural* changes of environment, but hardly with the active interference of human intelligence possessing designs of its own in no manner subordinated to the slow and gradual processes of natural development.

Similar considerations apply to the probable effect on animal life of any considerable relative displacement of oxygen from the atmosphere. We know that any—even the smallest—relative increase of carbonic acid is injurious to the life-sustaining quality of air, not necessarily on account of any actively poisonous qualities of its own, but by its displacement or dilution of oxygen, and that an atmosphere containing but eighteen per cent. by weight of oxygen, is incapable of supporting combustion and closely assails the limits of mammalian life.

If an animal possessing a given extent of lung surface and passages must, as now constituted, transmit through those passages 100 lbs. of air to obtain the necessary 23 lbs. of oxygen, then if some appreciable quantity, say for example, one per cent. by weight of CO_2 be added to the atmosphere, the animal must pass through its organs 101 lbs. of air to obtain the same reparatory result, and so on, in similar proportion, and this result will be accelerated if such addition of carbon dioxide be accompanied by the positive abstraction of oxygen as in the case of the combustion of fixed carbon. But under the continuing effects of diminishing oxygen and increasing carbon dioxide, there must come a time when the growing atmospheric modification can no longer be met by adaptation of individuals, but only by a permanent increase of the rapidity of respiration, or an established enlargement of the respiratory organs; and an animal materially and permanently changed in either respect would amount to a new form, adapted to the new conditions but unable to exist in the old, and only producible by the extinction of existing species no longer fit, and the evolution of favorable variations into new species.

Hence if it seems probable that existing types of vegetation could only absorb materially increased quantities of carbon by developing specific and generic changes, we may with still more confidence conclude that animals adapted to prevailing atmospheric conditions, can only acquire the necessary modifications of their respiratory and associated organs by means equally radical. As the principal air-breathing forms, including most reptiles and all birds and mammals, slowly succeeded the atmospheric changes of the carbon-fixing period, so under the influence of converse modifications it seems justly inferable that they being the most specialized and least adaptable as individuals, must in turn give place to specific substitutions.

Of course the extent of modification in cellular surface or rapidity of respiration to which existing forms can adapt themselves without such specific destruction and substitution, must chiefly be learned from actual experiments by competent hygienists.

But whatever may be the value of such speculations upon ultimate consequences, it is certain that with the large and constantly accelerating increase in the annual rate of production and consumption of coal, and the growth of population stimulated by its use, it must soon be carefully sought for in every accessible quarter of the world ; and it cannot be many years before such information will be possessed as may enable us to dispense with most of the hypotheses now required, and bring the entire subject of its quantity and duration more or less within the limits of exact computation.

The present object of this paper scarcely aims at more than the hastening of such researches, and quickening the interest of more competent analysts and naturalists.